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TELEMETERING BY RADIAL SCAN TELEVISION METHODS

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by

John Jamgochian, Jr.

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TELEMETERING BY RADIAL SCAN TELEVISION METHODS

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I wish to express my sincere appreciation to Professor Martial A. Honnell, not only for his suggestion of the problem, but also for his guidance and encouragement in its prosecution.

SUMMARY

This thesis describes the development of a radial-scan type television system for telemetering purposes. Factors of reduced bandwidth, use of standard electronic components, and less complex equipment than existing standard industrial television systems are advantages offered by this telemetering method.

The operation of the entire telemetering system may be described as follows: A varying sinusoidal voltage fed in quadrature to the deflecting plates, or coils, of a cathode-ray tube produces a spiral-scan pattern. A phototube, placed in direct view of the scan in front of which the object to be televised is placed, produces a current proportional to the light intensity received, as governed by the translucency of the object. The output of the phototube is fed, via a transmitting medium, to the control grid of a second cathode-ray tube, whose cathode trace is in perfect synchronism with that of the first cathode-ray tube, and reproduces an image of the object televised.

A working model of the complete radial-scan television system operated successfully when linked by direct cable and produced a satisfactory image reproduction of the transmitted information. A radio link would achieve identical results.

It is believed that this radial-type telemetering system offers the features of simplicity, flexibility, and reliability in applications where it is desired to transmit several meter readings for direct instantaneous viewing. Furthermore, the information to be transmitted would not be restricted solely to meter arms and meter calibrations, but

could also include the transmission of photographic slides.

Since the telemetering system is fundamentally a single-line-scan television system, all scanning and reproduction arrangements employed in television and facsimile systems are directly applicable.

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CHAPTER I

INTRODUCTION

An electric telemeter is defined by the American Standards Association to be "the complete measuring, transmitting and receiving apparatus for indicating, recording or integrating at a distance, by electrical translating means, the value of a quantity". A basic telemetering system comprises three parts: a transmitting device which converts the measured quantity into an electric signal; a wire or radio circuit which conveys the signal to a convenient location; and a receiving device which indicates, or records, the magnitudes of the measured quantity.

Historically, simple electric telemetering systems were patented as early as 1885. A primitive telemetering system commonly used in automobiles is the gasoline level indicator which employs a float mechanically arranged to vary a resistor connected in series with the car battery and the gas gage on the dashboard. The resultant deflection of the gas gage is proportional to the volume of gasoline in the gas tank. For many years power companies have employed telemetering systems to indicate at a central control point the voltage, current and power supplied by a remote generating plant. The fact that several hundred patents have been granted in telemetering is a good criterion of the importance and magnitude of the field.

In many telemetering applications, it is necessary to transmit several meter readings simultaneously over a single pair of wires, or over a single microwave radio circuit. Needless to say, some of these systems consist of rather complex electronic circuitry, which can be operated and maintained only by highly trained personnel.

For telemetering over short distances, a separate wire circuit may be economically justified for each measurement message to be transmitted. However, for long-distance telemetering over wires, or for telemetering over a radio link, special techniques have been developed to transmit a group of messages simultaneously, or sequentially, over a single channel.

Factors of importance in telemetering systems vary with the particular application, but the factors of basic importance to all telemetering systems are: accuracy of measurement, reliability, type of data presentation, initial cost and cost of operation.

CHAPTER II

ORIGIN AND PROPOSED SOLUTION OF PROBLEM

Background.--Development of the Radial Scan Television System originated during the concluding phases of a single-line-scan telemetering system during the winter of 1952.[1] At that time comprehensive work was being devoted to a type of telemetering system that utilized the circular sweep generated on the face of a cathode-ray tube as its basic light scanning source. Essentially, this telemetering system utilized single-line-scan television principles.

The following description of the single-line-scan system will give the reader a clearer understanding of the radial scan television system for telemetering purposes. Reference will be made to Figures 1(a) and 1(b).

Figure 1(a) is a sketch of the transmitting unit showing the physical relationship of the transparent meter scale, its associated meter movement, and a reference marker as they are related to the circular cathode-ray trace. It can be seen that all the information needed for reproducing a meter reading is collected during one line of scan. Figure 1(b) shows the basic set-up for transmitting and reproducing the intelligence scanned by this single circular trace.

In Figure 1(b), the sweep circuit represents the common quadrature voltage source from which the horizontal and vertical deflection plates,

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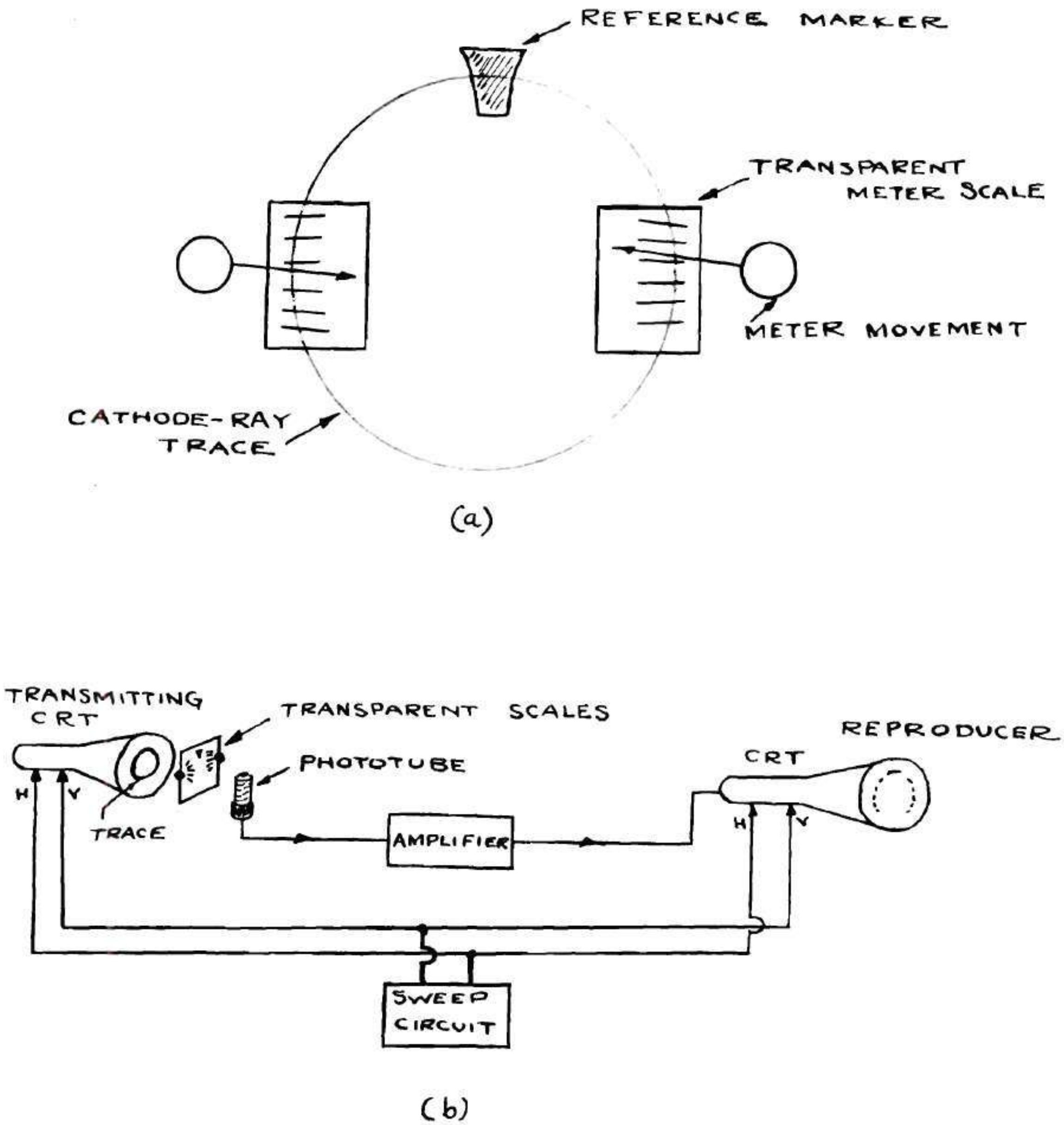
[1] M. A. Honnell, J. Jamgochian, and R. E. Humphrey, "Telemetering by Television Means," The Research Engineer, Vol. No. 7, April, 1953, p. 3.



SINGLE-LINE-SCAN TELEMETERING SYSTEM

FIGURE 1

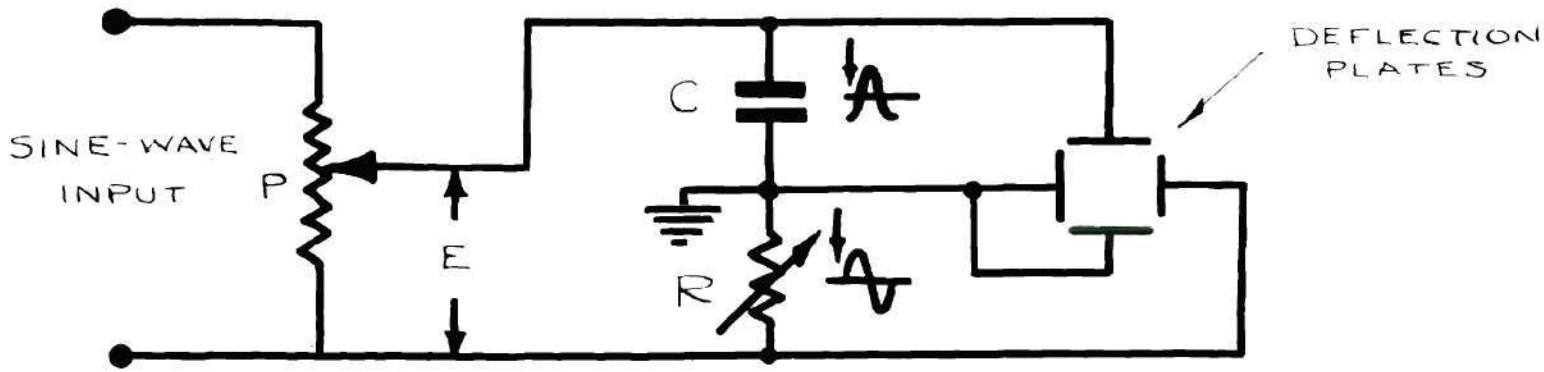
or coils, of the transmitter and receiver cathode-ray tubes receive their sweep voltage. This common sweep-voltage provides perfect synchronization between transmitter and receiver sections. A simple R-C quadrature network may be used to derive this circular sweep voltage from a sinusoidal source.

The luminous spot formed by the electron stream of the cathode-ray tube will trace a complete circle for each cycle of the applied voltage. When the spot passes beneath one of the opaque meter calibration lines, or under the meter pointer, the spot is momentarily hidden from view. It is apparent that the phototube, which is placed directly in front of the meters and the transparent meter scale, will receive light of constant intensity when the spot is in view, but this intensity of light will momentarily decrease each time the spot of light travels behind the opaque pointers and calibration marks. At the output of the phototube, the amplitude of the signal voltage generated varies in perfect synchronism with the variations in light intensity. These signals are further amplified and fed to the control grid of the receiving cathode-ray tube for image presentation. Since the circular spot sweeps, of both cathode-ray tubes are rotating in synchronism, the receiving cathode-ray tube will reproduce a faithful image of the light traces picked up by the phototube.

It is apparent that the entire face of the cathode-ray tubes could be scanned by this single line trace if the radius of this circular trace were made to vary continuously between predetermined limits thereby sweeping a spiral pattern on the screens of the cathode-ray tubes. Furthermore, the information to be transmitted would not be restricted soley to meter arms and meter calibrations, but could also include the transmission of photographic slides. The development of an apparatus which would produce this radial type of scan was essentially the basic problem to be solved in developing a radial scan television system.

Minimum Requirements for a Radial Type Scan.--An arrangement which will produce a radial type scan is shown in Figure 2. The sine-wave voltage, E, obtained from potentiometer, P, is applied to a phase shifter consisting of resistor, R, and the capacitor, C. The voltage across either element differs in phase from that across the other by 90 degrees. When resistor, R, is adjusted so that its resistance is equal to the reactance of capacitor, C, the two voltages are of equal amplitude. Since the voltages on the horizontal and vertical deflection plates are equal in magnitude and are in time quadrature, the electron beam of the cathode-ray tube will trace a perfect circle on its screen for each cycle of voltage applied from the sinusoid voltage source.

The potentiometer, P, controls the magnitude of the sine-wave voltage applied to the phase-shifting circuit. If P supplies a large voltage, then the voltage across both R and C will be large. Consequently, the circle traced on the screen will be of large diameter. Therefore, the magnitude of the voltage applied to the deflection plates determines the diameter of the circle. If the potentiometer is moved back and forth by a synchronous motor operated from the same source from which the deflecting plates are energized, the radius of the circle traced is varied continuously, and the pattern will be a spiral. The potentiometer and synchronous motor can be replaced by an electronic circuit which will modulate, or vary in amplitude, the sine-wave voltage. If the modulating voltage is a sawtooth voltage, whose frequency is a subharmonic of the carrier frequency,



BASIC RADIAL SCAN CIRCUIT

FIGURE 2

a spiral trace without retrace lines will appear on the face of the cathode-ray tube.

Basic Problem.--The major problem was to develop the electronic equipment necessary to produce the spiral trace. In order to demonstrate the complete telemetering system several additional electronic devices which are described later were developed. Since in any telemeter system simplicity is of importance, the following goals were kept in mind: elimination of duplication of transmit and receive circuitry and equipment; minimization of tube types; use of standard components; and terminal board construction for ease in maintanence.

Summary:--The operation of the entire system may be summarized as follows: A varying sinusoidal voltage in quadrature fed into the deflecting plates, or coils, of a cathode-ray tube produces a spiralling scan pattern. A phototube, placed in direct view of this scan and the object to be televised, produces current proportional to the light intensity received, as governed by the translucency of the object. The output of the phototube is fed via a transmitting medium to the control grid of a second cathode-ray tube, whose cathode trace is in perfect synchronism with the first cathode-ray tube, and reproduces an image of the object televised.

CHAPTER III

GENERAL DESCRIPTION OF THE SYSTEM

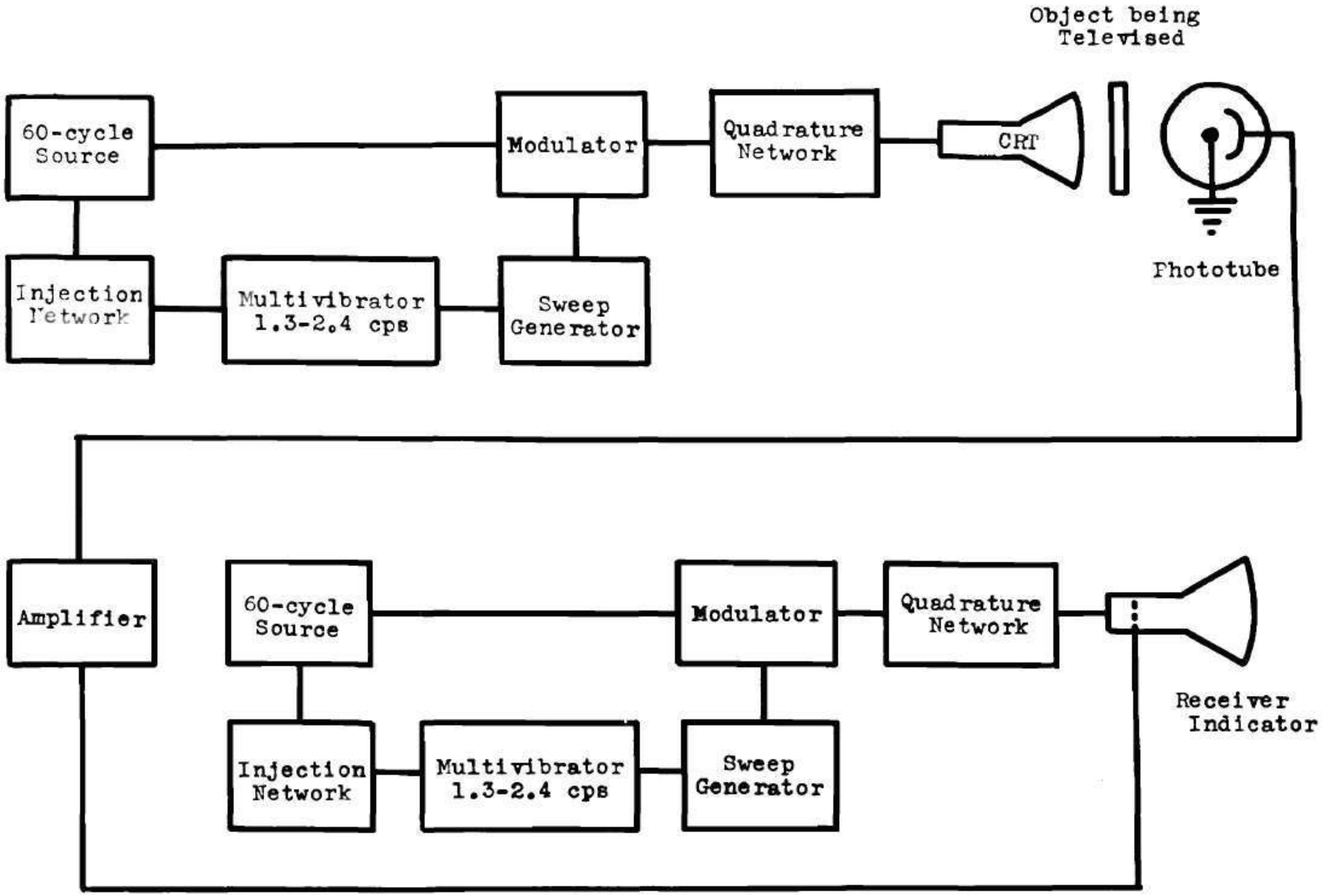
Without reference to detailed circuitry a general description of the television system will be discussed with the aid of the block diagram shown in Figure 3.

Transmitter.--The 60-cycle voltage source, shown in Figure 3, is obtained directly from the 60-cycle power system. This supplies the modulator with its carrier frequency. It is from this source that the basic rotating sweep is derived. In addition, the 60-cycle sine-wave source furnishes the synchronizing voltage to the multivibrator. The injection network permits the magnitude of the synchronizing voltage to be varied so as to facilitate the synchronization of the multivibrator to a submultiple frequency of the 60-cycle carrier voltage.

The output waveform of the asymmetrical multivibrator provides the triggering pulses to the sweep generator circuit. This pulse-controlled sawtooth voltage is fed into the modulator circuit thereby furnishing the modulating source necessary in producing a modulated sawtooth carrier, subharmonically related to the carrier frequency.

The modulated sawtooth voltage obtained from the modulator circuit is passed through the quadrature network and produces two voltages equal in magnitude and in time quadrature.

This quadrature voltage is fed to the deflection plates of the cathode-ray tube thereby causing the cathode-ray electron stream to generate a spiralling pattern on the fluorescent screen. Furthermore, the



BLOCK RADIAL SCAN TELEVISION SYSTEM

FIGURE 3

luminous cathode-ray spot traces a complete circle for each cycle of the applied quadrature voltage. Since the amplitude of the circular sweep voltage is modulated, or varied in amplitude, the radii of the circular traces is varied continuously between limits predetermined by the degree of modulation of the carrier.

The phototube, placed in front of the cathode-ray screen, receives a constant intensity of light unless the path of the light is blocked, or impeded, by an opaque object. At the output of the phototube, the amplitude of the signal voltage generated varies in perfect synchronism with the variations in light intensity. In general, no optical system of lenses is required with this type of pickup.

The resulting signal voltage is further amplified and transmitted by radio, telephone, or other communicating medium to a remote point for image reproduction.

Receiver.--The scanning system of the receiving section is similar to that employed in the transmitting section. In the receiver the signal voltage from the phototube is used to modulate the intensity of the beam at the cathode-ray tube.

In view of the fact that synchronizing voltage at the transmitter and receiver are obtained from the same frequency source, perfect synchronization is insured.

It should be mentioned that the frequency stability of the conventional 60-cycle power station is maintained within such tolerance that one could consider the frequency source as constant for any practical purpose. Since power companies east of the Mississippi, excluding the New England States, are interconnected, an assurance of 60-cycle per second is maintained throughout this area, but in the event a particular power company or station loses its reference frequency, from overloading reasons, a recovery rate, under normal conditions, not to exceed 1/200th of a cycle per second is maintained until the rate of 60 cps is obtained.[2] This service is restored by mutual agreement of the interconnected power companies at a predesignated time. This frequency stability assures exact synchronization of both transmitting and receiving systems.

Referring to the receiver section of Figure 3, similar action, as described for the transmitter portion, can be traced for the spiral-producing circuits.

Image Reproduction.--A signal voltage from the phototube is amplified by the amplifier, Block No. 10, and fed directly into the grid circuit of the receiver cathode-ray tube for Z-modulation. A choice of either positive or negative image reproduction on the fluorescent screen may be controlled by the design of the amplifier.

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[2] Information obtained from Robert J. Cooper, Georgia Power Company Protection Engineer and representative to the Interconnected Electric Power System serving central United States.

CHAPTER IV

CIRCUIT DESCRIPTION

This chapter is devoted to the description of the circuits used in the final model of the Radial Scan Telemetering System.

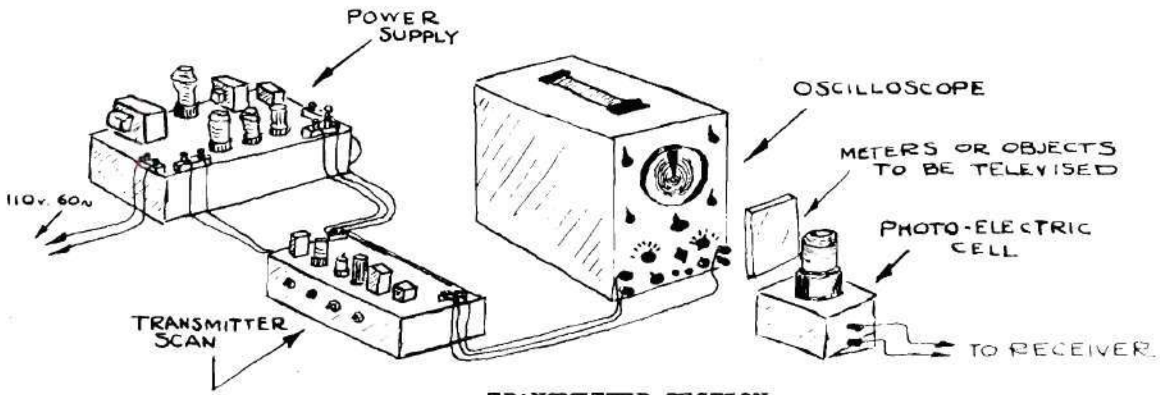
A composite illustration of the complete transmitting system is shown in Figure 4. A separate power supply was used to energize the transmitter, and a conventional cathode-ray oscilloscope was used to display the spiralling scan. Figure 5 is an illustration of the complete receiving section

Transmitter Section

Multivibrator.--The asymmetrical multivibrator shown in Figure 6 employs a 6SN7 double-triode and the necessary circuit constants to produce a natural oscillating frequency in the vicinity of 1.5 cycles per second. Standard design equations were employed for computing the various circuit element values.

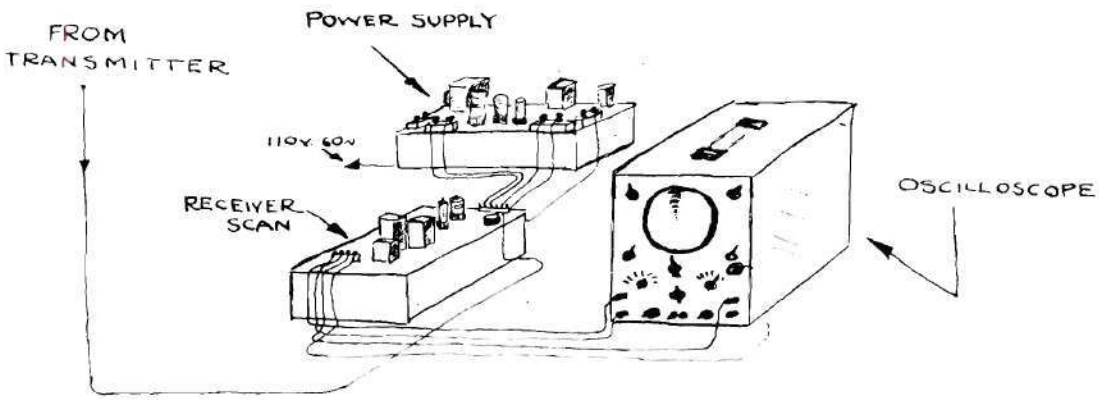
Referring to the block diagram, Figure 6(a), and its circuit configuration, Figure 6(b), a general layout of the circuits is established in addition to the actual circuitry involved.

The transformer, T_1, supplies the carrier frequency for the modulator and provides the synchronization voltage for the multivibrator. The latter voltage is developed across potentiometer, R_{18}, from which the desired magnitude of synchronizing voltage may be injected into the multivibrator plate circuit, via R_{19}. Attention should be called to the fact that greatest locking sensitivity was achieved when the 60-cy-



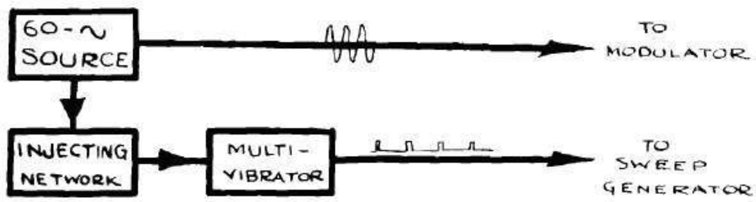
TRANSMITTER SECTION

FIGURE 4

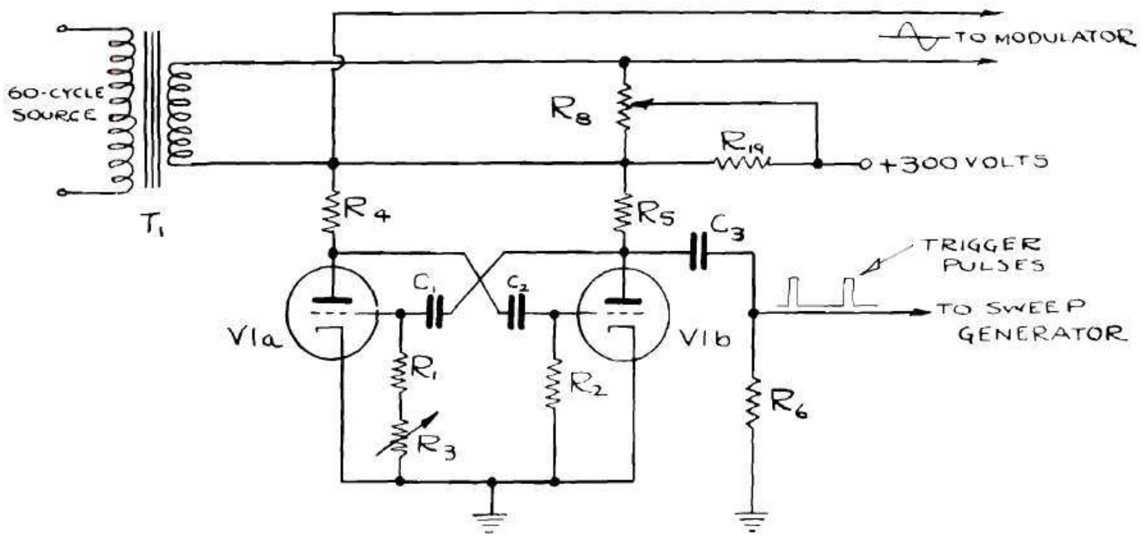


RECEIVER SECTION

FIGURE 5



(a) BLOCK DIAGRAM



(b) CIRCUIT DIAGRAM

MULTIVIBRATOR, INJECTING NETWORK, AND 60-CYCLE SOURCE

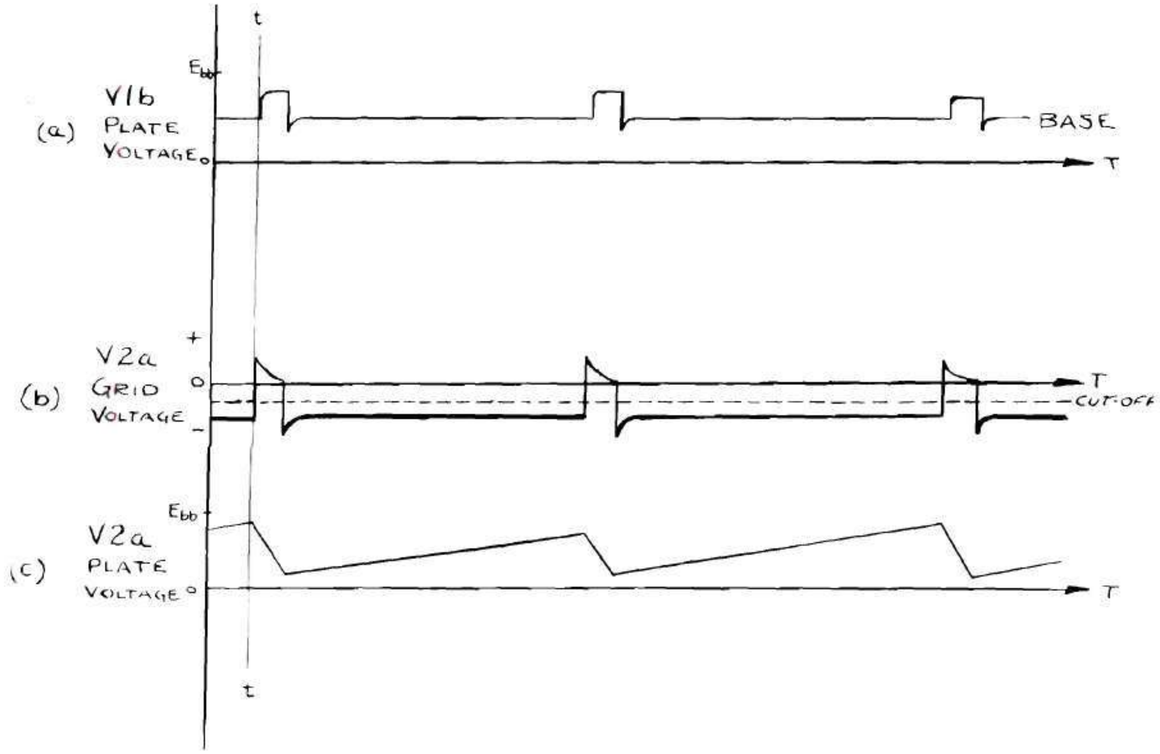
FIGURE 6

cle synchronizing voltage was injected into the grid circuit, but more desirable results were obtained when the synchronizing voltage was induced in the plate circuit of the multivibrator.

It was desirable to obtain pulses of short duration with a relatively long period of time between pulses. The time constant, $(R_1 + R_3)C_1$, in the grid circuit of tube V1a was made long with respect to the time constant, R_2C_2, of tube V1b, so that the latter tube remained cut off for only a small portion of the cycle. This action, at the plate of tube V1b, allowed plate current to flow through resistor, R_5, causing a voltage drop for a time equal to the cut off period of tube V1a. This resulting voltage waveshape is shown in Figure 7(a).

Sweep Generator.--For this application it is desirable to have a sweep voltage which is rigidly controlled by a pulse generator. This is accomplished by a sweep generator which uses a vacuum tube to control the charging and discharging of a capacitor. This type of sweep circuit is not a relaxation type of oscillator, since its action is controlled entirely by the grid, and no conduction is possible until the grid bias permits it, irrespective of how high the capacitor voltage may rise.

Since controlled pulses of subharmonic relation to the 60-cycle carrier frequency are generated from the asymmetric multivibrator, these periodic waveforms serve as the triggering source for the sweep generator and thereby govern the origin time and sweep back of each sawtooth waveform generated. Since the operation of the sweep generator is rigidly controlled by these trigger pulses, the resulting period of the sawtooth waveforms will inherently be related to the 60-cycle carrier frequency by the same subharmonic relation as the period of the unbalanced multivi-



WAVEFORMS

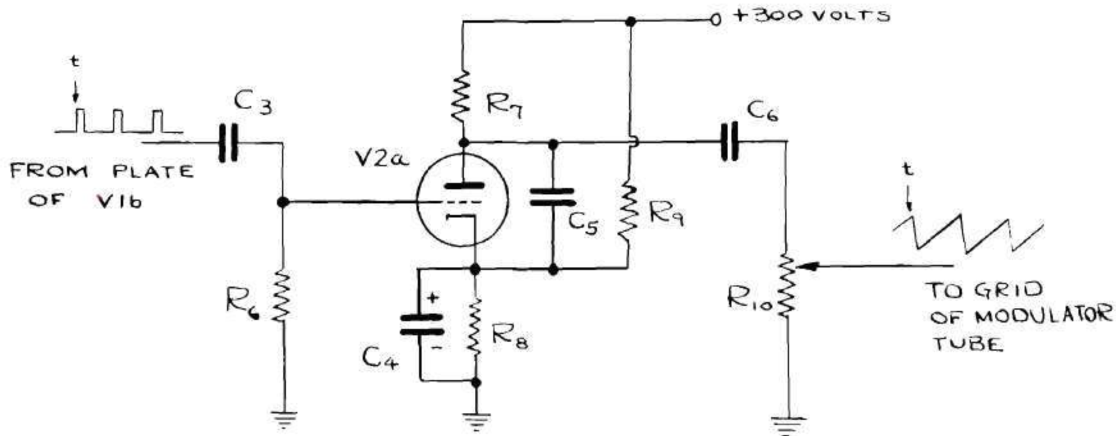
FIGURE 7

brator. The input and output waveforms are shown in the circuit diagram of Figure 8.

The pulse voltage is coupled into the grid of the sawtooth generator tube, V2a, through capacitor, C3. This triggering pulse comprises approximately 5 per cent of the cycle and has a magnitude of approximately 120 volts.

Figure 7 is a sketch of the waveforms associated with the sweep generator. At a time, t, the leading edge of the trigger pulse is applied to the grid of tube V2a and drives the grid positive. At that instant the grid draws current which partially charges capacitor, C_3. The trailing edge of the trigger pulses causes the grid to be driven negative thus driving the tube beyond cut off. Normally, tube V2a is in a non-conducting state since its cathode is biased far below cut-off by the voltage divider network consisting of R_8 and R_9. When tube V2a is cut off, the sweep generator capacitor, C_5, begins to charge through resistor, R_7. The time constant of the charging circuit, R_7C_5, is extremely long as compared to the longest RC time constant in the grid circuit of the asymmetric multivibrator. The time constant of R_7C_5 was made much greater than the time constant of $(R_1 + R_3)C_1$ thus insuring that the voltage rise across capacitor, C_5, will be well within the linear portion of the charging curve of the capacitor.

The capacitor voltage of C_5 rises exponentially toward the value of the source potential; however, at some time long before capacitor, C_5, is charged to supply potential, another positive trigger pulse is applied to the grid of tube V2a. This pulse will cause the triode to conduct heavily, and capacitor, C_5, will be discharged during this positive pulse



PULSE-CONTROLLED SWEEP GENERATOR

FIGURE 8

interval. Since the resistance of the tube is very low during this condition, capacitor, C_5, will discharge rapidly through tube V2a, and a sawtooth voltage will appear across C_5.

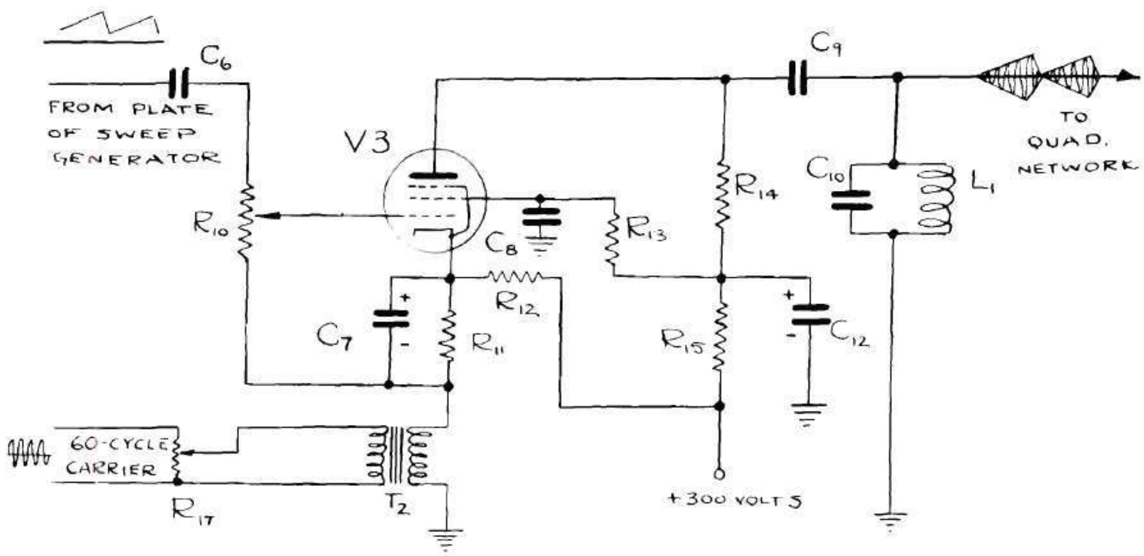
The resulting sawtooth voltage, which constitutes the modulating voltage, is taken off between the plate of V2a and ground, rather than across capacitor, C_5. This sawtooth waveform appears at these two places since the impedance of the by-pass capacitor, C_4, causes the cathode side of capacitor, C_5, to be practically at ground potential for a-c voltages.

Modulator.--The operation of the modulator circuit shown in Figure 9 is of type commonly employed in receivers. Other type of modulator systems were tried but the cathode system of carrier injection was the only system yielding 100 per cent modulation. This was of importance since the degree of modulation output determines the inner and outer limits of the radial scan pattern.

On Figure 9 is shown a composite picture of the input and resultant waveforms of the modulator circuit. Briefly, a 60-cycle carrier voltage is modulated by a sawtooth voltage having a frequency which is a submultiple of 60-cycles, resulting in a modulated carrier with a sawtooth envelope.

The 60-cycle carrier is introduced in the cathode circuit via transformer, T_2 and the voltage divider, R_{17}, while the modulating sawtooth voltage is coupled into the control grid circuit by capacitor, C_6. Potentiometer, R_{10}, controls the input magnitude of the modulating voltage.

The resulting voltage from the plate of modulator tube V3 is coupled into the tank circuit, L_1C_{10}, by capacitor, C_9. The parallel



MODULATOR

FIGURE 9

resonant circuit tuned to 60-cycles is a filter which passes the 60-cycle carrier and its significate side-bands.

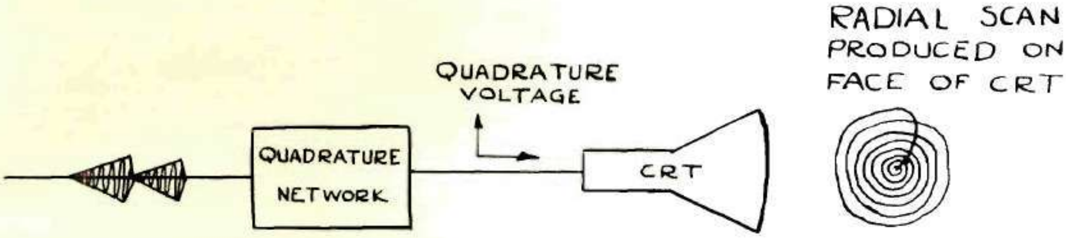
Since an extremely low frequency modulating source was being employed, there was a tendency for the plate voltage of the modulator to pulsate in synchronism with the frequency of the sawtooth voltage. This resulted in a slight rise at the beginning of each sawtooth variation which further resulted in the distortion of the final modulated voltage.

A low frequency compensating RC network consisting of R_{15} and C_{12} was placed in series with the plate load resistor, R_{14}, eliminating the pulsating action of the modulator supply voltage. In addition to stabilizing the supply potential, a more symmetrical return of the 60-cycle carrier to its zero or center line potential resulted.

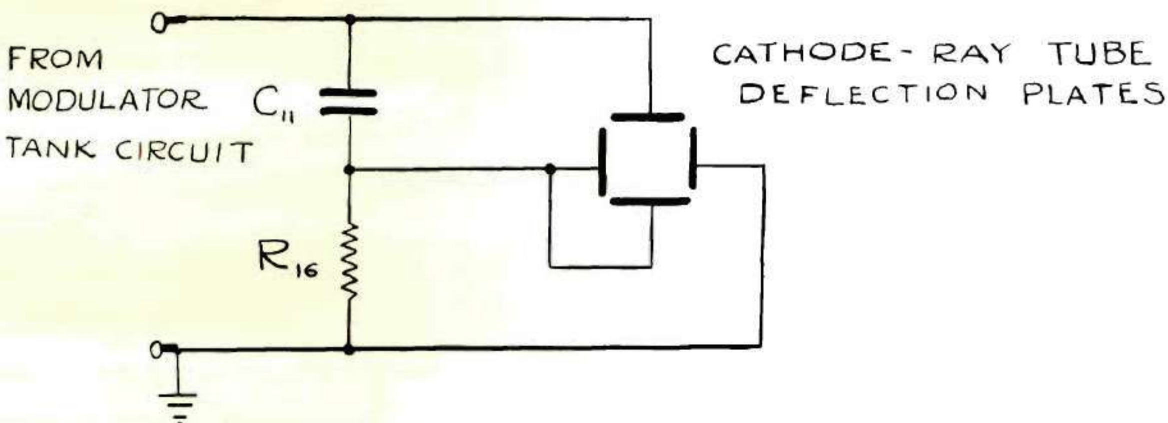
Quadrature Network.--The modulated voltage obtained from the tank circuit of the modulator is applied to the quadrature network. Figure 10(a) is a block diagram showing the waveforms entering the quadrature network and resulting display on the face of the cathode-ray shifter.

The voltage drop across the resistor, R_{16}, is 90 degrees out of phase with that across the capacitor, C_{11}. The magnitude of these voltages are made equal by adjusting R_{16} so as to equal the reactance of C_{11}.

Cathode-Ray Tube.--With the output of the quadrature network connected as shown in Figure 10(b), a varying voltage in quadrature relation is impressed on the horizontal and vertical deflection plates of the cathode-ray tube resulting in the luminous cathode-ray spot tracing a stationary spiral pattern on the fluorescent screen. Figure 11 is a photograph of the radial display.



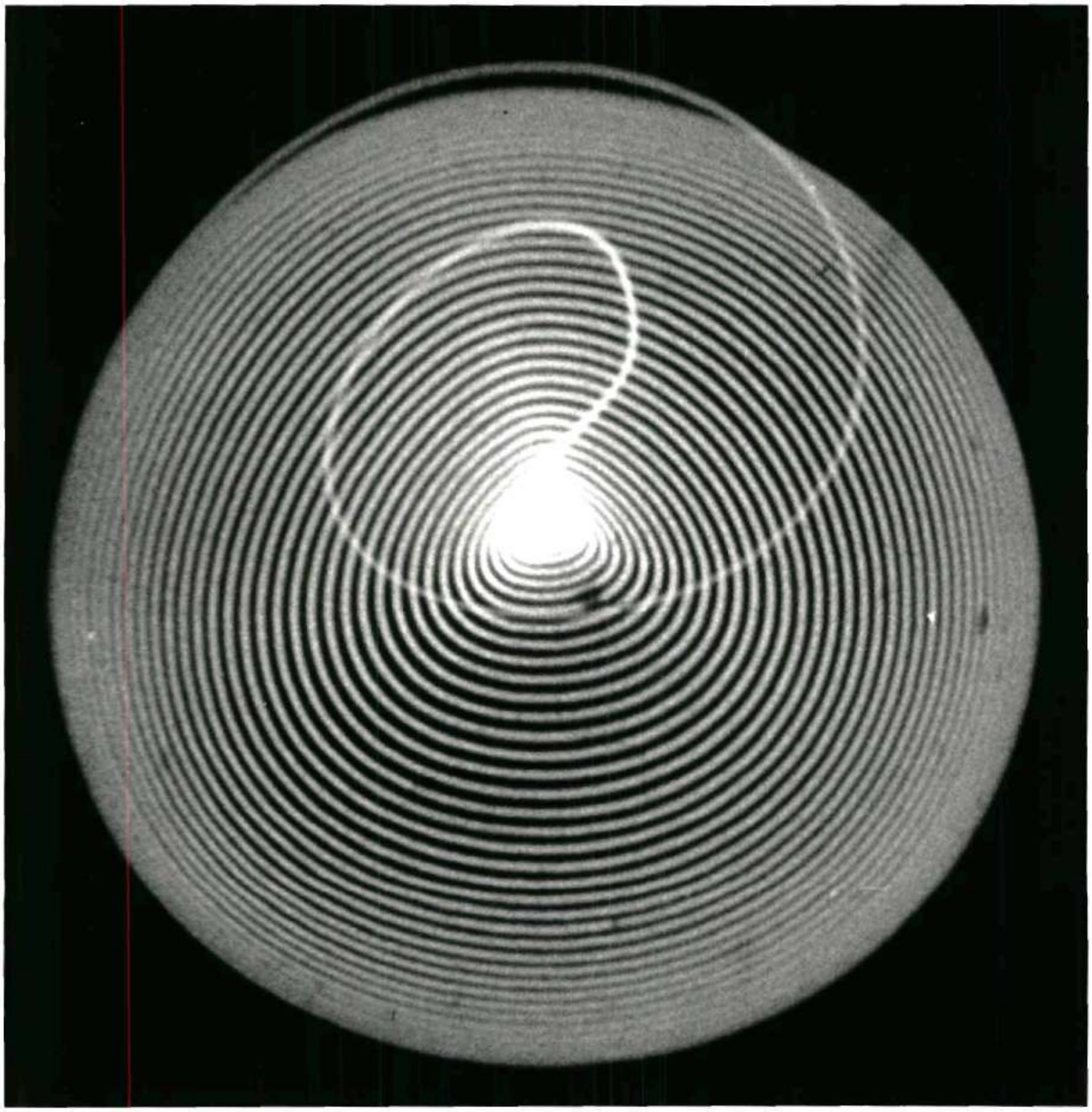
(a) BLOCK DIAGRAM



(b) CIRCUIT DIAGRAM

QUADRATURE NETWORK AND CATHODE-RAY TUBE

FIGURE 10



RADIAL SCAN

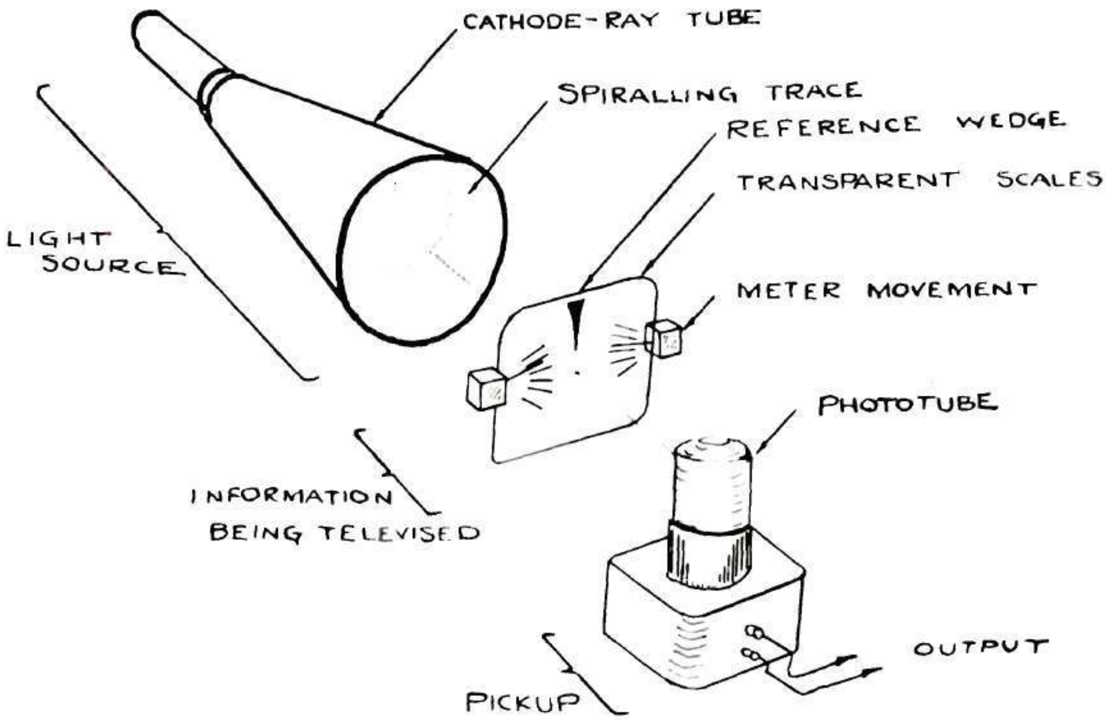
FIGURE 11

<u>Basic Light Source</u>.--The expanding and collapsing action of the radial scan serves as the basic light source which is intercepted by the meter calibration marks and pointers. Figure 12 will help give a better understanding of the operation during scanning. Relative positions of the cathode-ray tube, the information being televised, and the phototube are shown.

For each cycle of the scanning voltage the luminous spot traces a complete circle on the face of the cathode-ray tube. The phototube, placed in direct view of the spiralling cathode-ray trace and the information being televised, is illuminated by light of relatively constant intensity except at instants when the luminous spot is interrupted by the object being televised. The resulting output of the phototube is a signal voltage which varies in perfect synchronism with the light variations received at the pickup phototube. Notice that a reference wedge is placed near the meter scales; this is to provide a well-defined marker at the receiver indicator to identify the meters. No optical system of lenses was used in the working model.

The resulting signal voltage is transmitted by some convenient medium to a distant point for a complete shadow image of the meter calibrations and pointers.

It should be mentioned that in producing the radial scan, it is theoretically impossible to obtain a light source of uniform intensity without compensation since the linear velocity of the spot is not constant. Visually, this is unnoticeable since the electron beam moves at such a slow speed the luminous spot is always at maximum light intensity. Furthermore, the negative method of image reproduction eliminates the neces-



LIGHT SOURCE, INFORMATION BEING TELEVISED, AND PICKUP

FIGURE 12

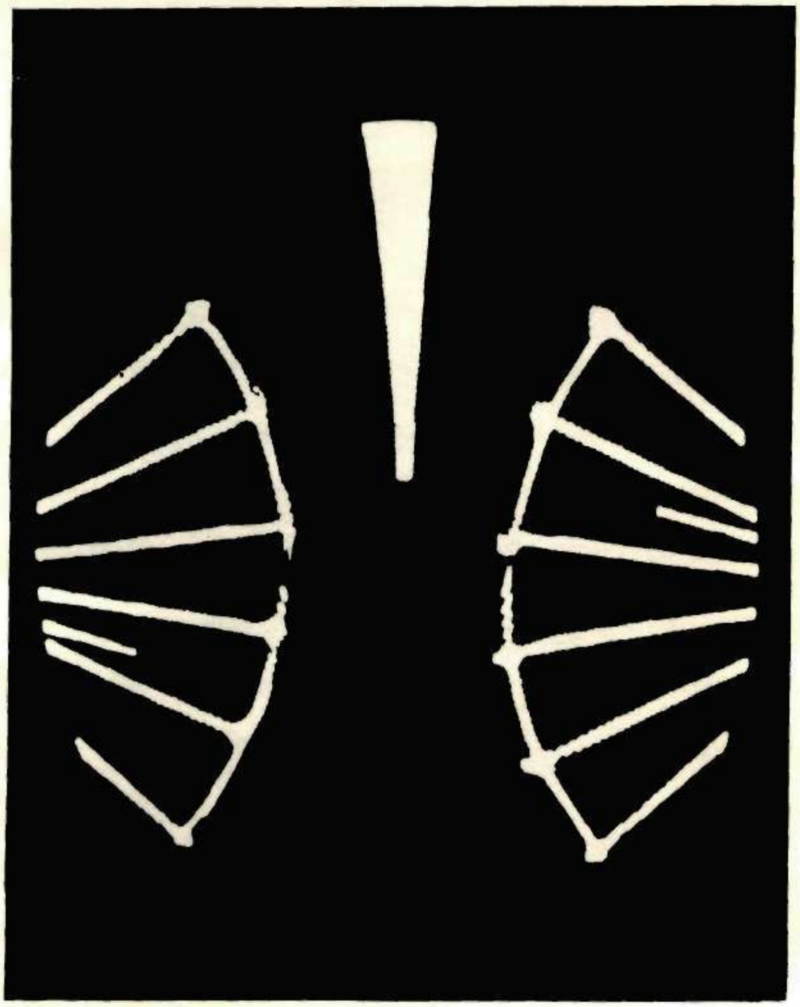
sity of any compensation.

Receiver Section

Scanning Circuit.--The scanning circuits of the receiver section, which produce the radial display at the receiver indicator, operate in exactly the same manner as the spiral-producing circuits described in the transmitter section.

The process of synchronizing the receiver spiralling pattern to that of the transmitter was achieved by injecting the proper magnitude of synchronizing voltage in the receiver multivibrator circuits. Inspection of Figures 14 and 15, in the appendix, will relate the corresponding synchronous multivibrator frequencies of transmitter and receiver, respectively, for given magnitudes of injected voltages. Numerical investigation of the transmitter and receiver curves show that synchronization of modulating frequencies in the order of 1.395 to 2.4 cycles per second may be readily achieved. Potentiometer, R_3, in the receiver multivibrator circuit is a vernier frequency control and is extremely useful for final frequency synchronization. In the event the receiver is improperly synchronized, the received image will foldover.

Indicator Presentation.--It is possible to achieve positive or negative presentation by reversing the polarity of the signal voltage at any point from the output of the phototube to the grid of the receiver cathode-ray tube. Figure 13 illustrates a negative indicator presentation obtained in the completed system.



NEGATIVE PRESENTATION AT

RECEIVER INDICATOR

FIGURE 13

CHAPTER V

CONCLUSION AND SUGGESTIONS

The final working model of the radial scan telemetering system operated successfully when linked by direct cable and produced a satisfactory image reproduction of the transmitted information. A radio link would achieve identical results.

In the event that no 60-cycle voltage, from a common source, is available for transmitter or receiver sections, it is possible to use standard techniques to synchronize a 60-cycle oscillator at the receiver section with the incoming pulses from the transmitter.

Since the telemetering system described herein is fundamentally a single-line-scan television system, all scanning and reproduction arrangements employed in television and facsimile systems are directly applicable.

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APPENDIX I

DATA AND CURVES

TABLE 1

RESULTS OF TESTS FOR SYNCHRONIZING OF TRANSMITTER MULTIVIBRATOR

Frequency of injected voltage = 60 c.p.s.

Injected 60-cycle Voltage	Number of Radial Lines Per Sweep	Modulation Frequency (cycles/sec.)	Ratio = $\frac{\text{M.V. Frequency}}{\text{Injected Freq.}}$
0	75	0.80	0.01332
0.1	43	1.395	0.02323
0.25	42	1.428	0.0238
0.5	40	1.50	0.025
0.68	38	1.58	0.02635
0.75	38	1.58	0.02635
0.85	38	1.58	0.02635
1.0	36	1.668	0.0278
1.5	34	1.763	0.0294
1.95	32	1.874	0.03121
2.3	31	1.935	0.03222
2.5	30	2.0	0.0334
3.4	27	2.22	0.0370
3.6	26	2.305	0.0384
3.8	25	2.4	0.040
4.3	25	2.4	0.040
4.7	24	2.5	0.0417
4.95	24	2.5	0.0417

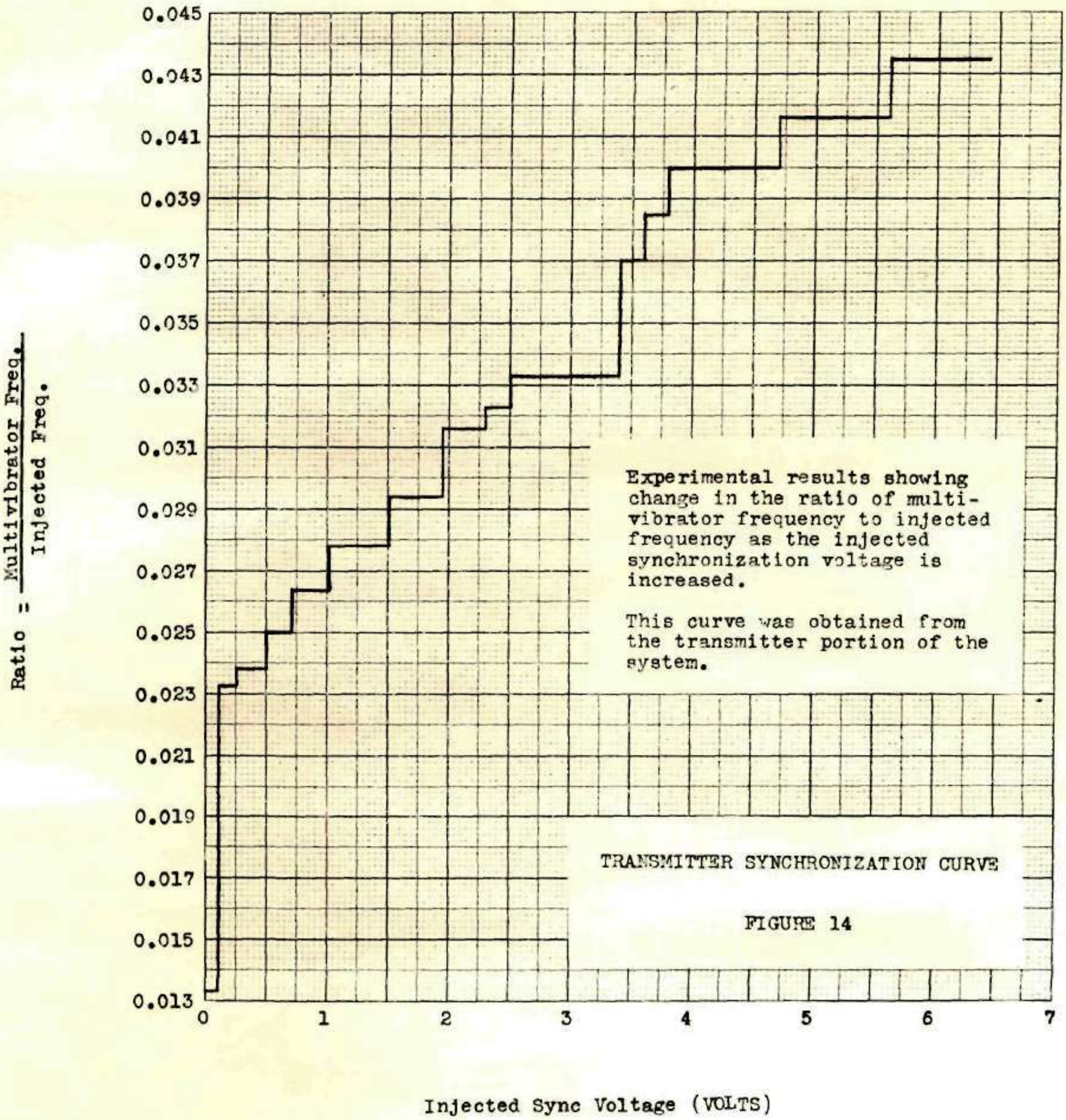
TABLE 1

RESULTS OF TESTS FOR SYNCHRONIZING OF TRANSMITTER MULTIVIBRATOR

Frequency of injected voltage = 60 c.p.s.

Injected 60-cycle Voltage	Number of Radial Lines Per Sweep	Modulation Frequency (cycles/sec.)	Ratio = $\frac{\text{M.V. Frequency}}{\text{Injected Freq.}}$
5.25	24	2.5	0.0417
5.6	23	2.61	0.0435
6.0	23	2.61	0.0435
6.3	23	2.61	0.0435
6.4	23	2.61	0.0435

Curves of Injected Voltage Vs $\frac{\text{Multivibrator Frequency}}{\text{Injected Frequency}}$ are shown in Figure 14.



TRANSMITTER SYNCHRONIZATION CURVE

FIGURE 14

TABLE 2

RESULTS OF TEST FOR SYNCHRONIZING OF RECEIVER MULTIVIBRATOR

Frequency of injected voltage = 60 c.p.s.

Injected 60-cycle Voltage	Number of Radial Lines Per Sweep	Modulation Frequency (cycles/sec.)	Ratio = $\frac{\text{M.V. Frequency}}{\text{Injected Freq.}}$
0.08	72	0.823	0.0137
0.2	72	0.834	0.0139
0.65	72	0.834	0.0139
1.0	70	0.858	0.0143
1.8	70	0.858	0.0143
3.0	68	0.883	0.0147
4.0	64	0.938	0.01562
5.8	60	1.0	0.0167
6.8	58	1.033	0.01726
8.0	56	1.071	0.0179
10.0	54	1.111	0.0185
12.0	47	1.277	0.02125
14.2	45	1.333	0.0222
15.8	43	1.395	0.02325
17.2	39	1.538	0.0256
18.8	36	1.668	0.0278

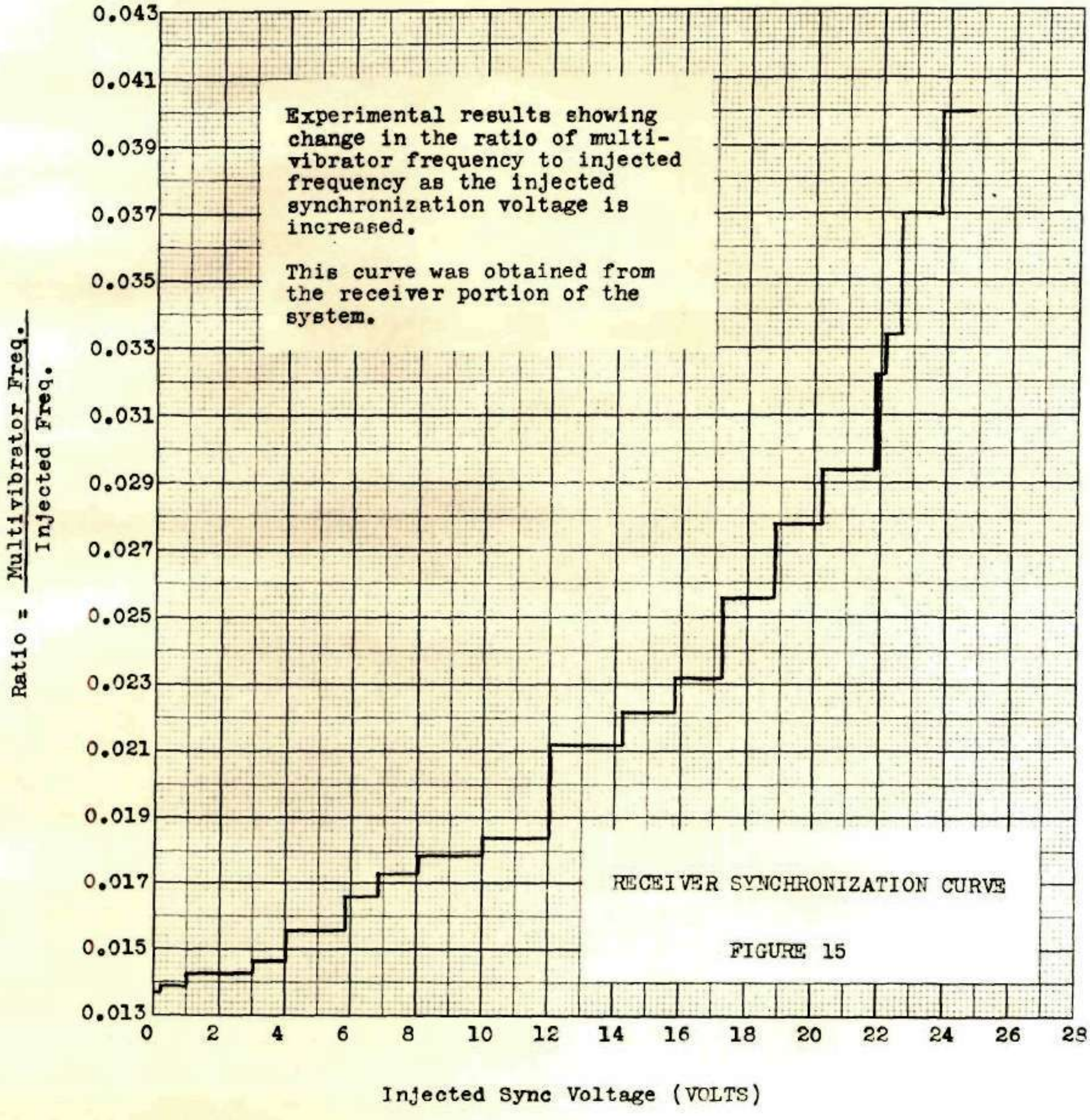
TABLE 2

RESULTS OF TEST FOR SYNCHRONIZING OF RECEIVER MULTIVIBRATOR

Frequency of injected voltage = 60 c.p.s.

Injected 60-cycle Voltage	Number of Radial Lines Per Sweep	Modulation Frequency (cycles/sec.)	Ratio = $\frac{\text{M.V. Frequency}}{\text{Injected Freq.}}$
20.2	34	1.763	0.0294
21.8	31	1.935	0.0322
22.1	30	2.0	0.0334
22.6	27	2.22	0.037
22.8	25	2.4	0.04

Curves of Injected voltage vs $\frac{\text{multivibrator frequency}}{\text{injected frequency}}$ are shown in Figure 15.

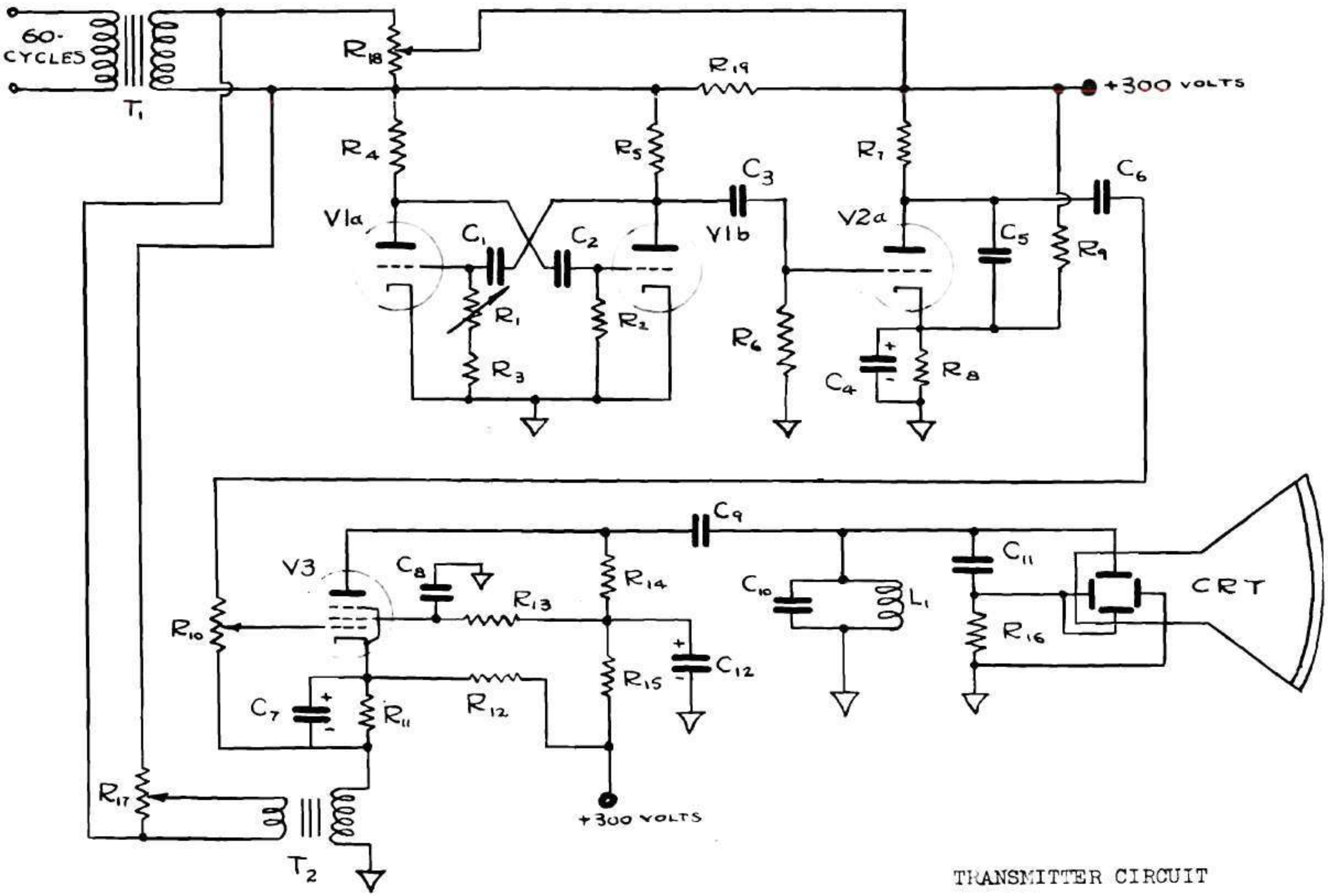


RECEIVER SYNCHRONIZATION CURVE

FIGURE 15

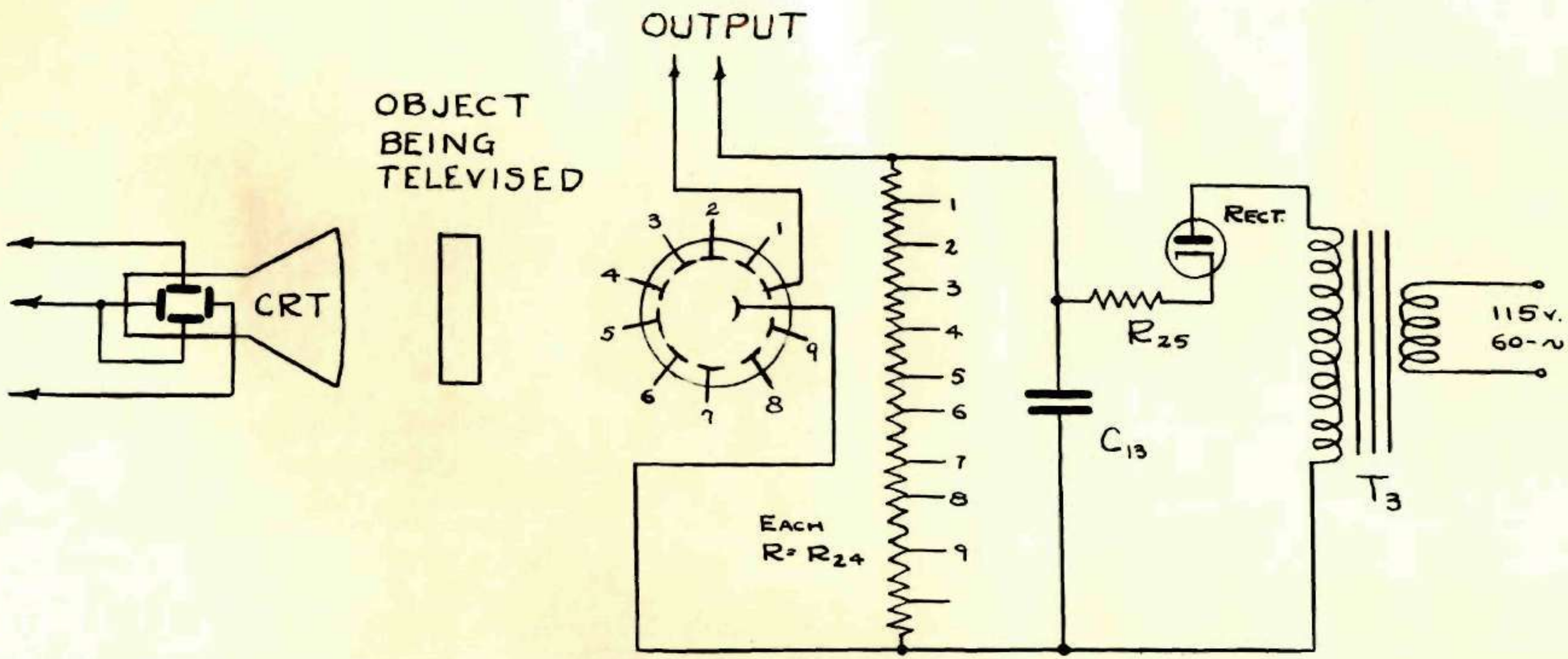
APPENDIX II

CIRCUIT SCHEMATICS



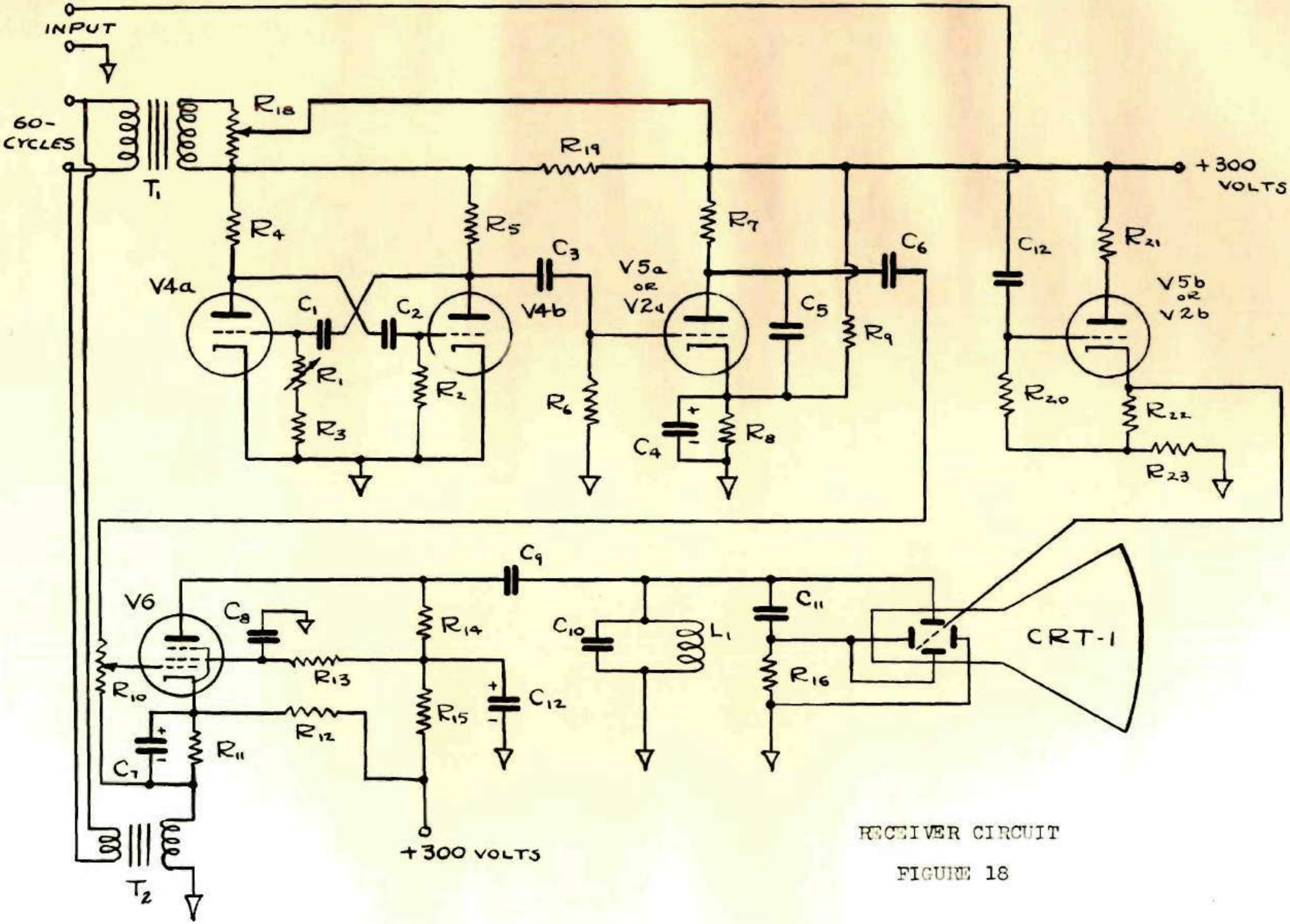
TRANSMITTER CIRCUIT

FIGURE 16



PHOTOTUBE CIRCUIT

FIGURE 17



RECEIVER CIRCUIT

FIGURE 18

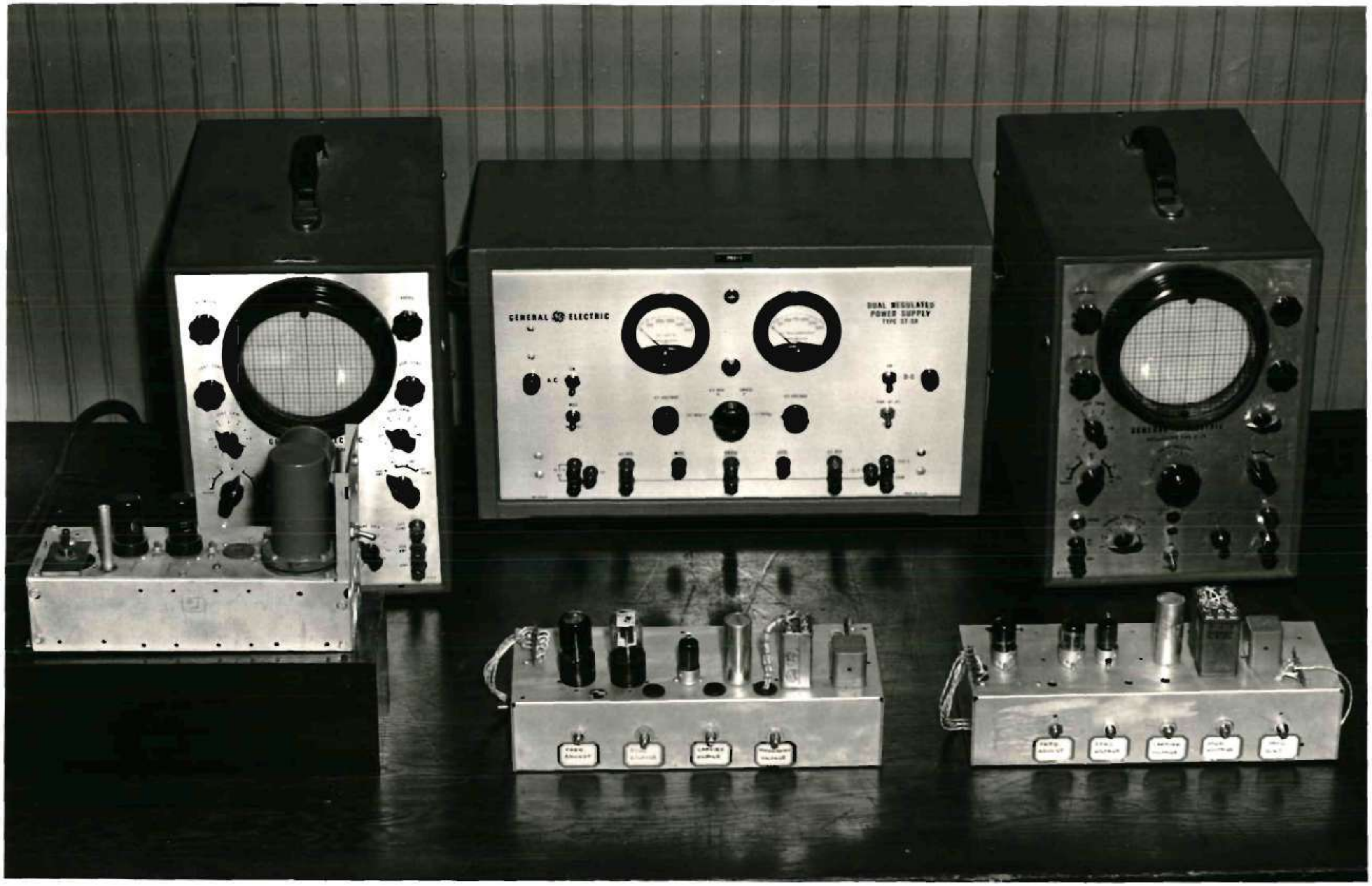
VALUE AND RATING OF COMPONENTS LISTED
FOR FIGURES 16, 17 AND 18

C_1 = 0.1 ufd|400 v.	R_5 = 100 K	R_{22} = 1.5 K	CRT = CRO
C_2 = 0.1 ufd|400 v.	R_6 = 100 K	R_{23} = 10 K	CRT - 1 = CRO
C_3 = 0.1 ufd|400 v.	R_7 = 1.0 M	R_{24} = 100 K	
C_4 = 145 ufd|25 v.	R_8 = 100 K	R_{25} = 5.6 K	
C_5 = 5 ufd|330 v.	R_9 = 1.0 M	L_1 = 52 henrys	
C_6 = 1.0 ufd|200 v.	R_{10} = 1.0 M	T_1 = 1:1 Ratio Audio Transformer	
C_7 = 145 ufd|25 v.	R_{11} = 20 K	T_2 = 1:1 Ratio Audio Transformer	
C_8 = 0.05 ufd|600 v.	R_{12} = 100 K	T_3 = Power Transformer	
C_9 = 0.1 ufd|400 v.	R_{13} = 270 K	V1a = $\frac{1}{2}$ 6SN7	
C_{10} = 0.15 uf|600 v.	R_{14} = 33 K	V1b = $\frac{1}{2}$ 6SN7	
C_{11} = 0.25 uf|600 v.	R_{15} = 3.3 K	V2a = $\frac{1}{2}$ 6SL7	
C_{12} = 0.01 uf|600 v.	R_{16} = 47 K	V2b = $\frac{1}{2}$ 6SL7	
C_{13} = 40 ufd|450 v.	R_{17} = 50 K	V3 = 6CB6	
R_1 = 0.5 M	R_{18} = 10 K	V4a = $\frac{1}{2}$ 12AU7	
R_2 = 100 K	R_{19} = 10 K	V4b = $\frac{1}{2}$ 12AU7	
R_3 = 4.7 M	R_{20} = 1 M	V5a = $\frac{1}{2}$ 12AX7	
R_4 = 100 K	R_{21} = 10 K	V6 = 6CB6	

All resistors are rated at 1 watt.

APPENDIX III

PHOTOGRAPH OF EQUIPMENT



PHOTOGRAPH OF EQUIPMENT

FIGURE 19